JC14 Rec'd PCT/PTO 06 NOV 2001

FORM PTO-1390 (REV. 5-93)	U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTORNEY'S DOCKET NUMBER **10191/2062**
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		U.S. APPLICATION NO. (If known, see 37 CFR 1.5) 10/009288

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED:
PCT/DE00/01399	**4 May 2000 (04.05.00)**	**06 May 1999 (06.05.99)**

TITLE OF INVENTION
METHOD AND DEVICE FOR ESTIMATING MEMORY-ENABLED TRANSMISSION CHANNELS

APPLICANT(S) FOR DO/EO/US
Frank KOWALEWSKI

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information.

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) immediately rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☒ has been transmitted by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. ☐ have. been transmitted by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☒ have not been made and will not be made.
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). (unsigned)
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A **FIRST** preliminary amendment.
14. ☒ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information: International Search Report (translated), Preliminary Examination Report and PCT/RO/101.

EXPRESS MAIL NO.: EV003627531US

U.S. APPLICATION NO. if known, see 37 C.F.R.1.5 10/009288	INTERNATIONAL APPLICATION NO. PCT/DE00/01399	JC13 Rec'd PCT/PTO 06 NOV 2001 ATTORNEY'S DOCKET NUMBER 10191/2062

17. ☒ The following fees are submitted:

Basic National Fee (37 CFR 1.492(a)(1)-(5)):

	CALCULATIONS	PTO USE ONLY
Search Report has been prepared by the EUROPEAN PATENT OFFICE or JPO $890.00		
International preliminary examination fee paid to USPTO (37 CFR 1.482) $710.00		
No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) $740.00		
Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO $1,040.00		
International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) $100.00		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 890	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$	

Claims	Number Filed	Number Extra	Rate		
Total Claims	12 - 20 =	0	X $18.00	$ 0	
Independent Claims	2 - 3 =	0	X $84.00	$ 0	
Multiple dependent claim(s) (if applicable)			+ $280.00	$	

TOTAL OF ABOVE CALCULATIONS =	$ 890	
Reduction by ½ for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 CFR 1.9, 1.27, 1.28).	$	
SUBTOTAL =	$ 890	
Processing fee of $130.00 for furnishing the English translation later the ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f)). +	$	
TOTAL NATIONAL FEE =	$ 890	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). $40.00 per property +	$	
TOTAL FEES ENCLOSED =	$ 890	
	Amount to be: refunded	$
	charged	$

a. ☐ A check in the amount of $__________ to cover the above fees is enclosed.

b. ☒ Please charge my Deposit Account No. 11-0600 in the amount of **$890.00** to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 11-0600. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

By: [signature] (Reg. No. 41,172)

Richard L. Mayer

SIGNATURE

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Richard L. Mayer, Reg. No. 22,490
NAME

11/6/01
DATE

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EXPRESS MAIL CERTIFICATE

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TYPE OF DOCUMENT National Phase Patent Application

re: Kowalewski, F.

SERIAL NO. To be Assigned FILING DATE Herewith

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Miran Soroka

(PRINTED NAME OF PERSON MAILING PAPER OR FEE)

Miran Soroka

(SIGNATURE OF PERSON MAILING PAPER OR FEE)

Method and device for estimating memory-enabled transmission channels

10/009288
JC13 Rec'd PCT/PTO 06 NOV 2001

[10191/2062]

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s)	:	Frank KOWALEWSKI
Serial No.	:	To Be Assigned
Filed	:	Herewith
For	:	METHOD AND DEVICE FOR ESTIMATING MEMORY-ENABLED TRANSMISSION CHANNELS
Art Unit	:	To Be Assigned
Examiner	:	To Be Assigned

Assistant Commissioner
for Patents
Washington, D.C. 20231
Box Patent Application

PRELIMINARY AMENDMENT AND
37 C.F.R. § 1.125 SUBSTITUTE SPECIFICATION STATEMENT

SIR:

Please amend the above-identified application before examination, as set forth below.

IN THE SPECIFICATION AND ABSTRACT:

In accordance with 37 C.F.R. § 1.121(b)(3), a Substitute Specification (including the Abstract, but without claims) accompanies this response. It is respectfully requested that the Substitute Specification (including Abstract) be entered to replace the Specification of record.

IN THE CLAIMS:

On the first page of the claims, first line, change "What is claimed is:" to:
--What Is Claimed Is:--.

Please cancel original claims 1 to 12, without prejudice, in the underlying PCT Application No. PCT/DE00/01399.

EV003627531US

Please add the following new claims:

13. (New) A method for estimating a memory-enabled transmission channel, comprising the steps of:

determining a first estimation $\underline{\hat{h}}$ of a pulse response of the memory-enabled transmission channel;

performing an estimation of an additive interference of the memory-enabled transmission channel; and

performing a correction of the first estimation while taking into consideration the estimation of the additive interference.

14. (New) The method according to claim 13, wherein:

the step of determining the first estimation is performed by a matched filter.

15. (New) The method according to claim 14, wherein:

the matched filter is given by

$$\underline{\hat{h}} = \frac{1}{\gamma} \cdot G^{*T} \cdot \underline{e}_{\mathrm{ref}},$$

where

$$G = \begin{pmatrix} r_W & r_{W-1} & \cdots & r_1 \\ r_{W+1} & r_w & & r_2 \\ \cdot & \cdot & & \cdot \\ r_{W+N-1} & r_{W+N-2} & \cdots & r_N \end{pmatrix}$$

and

$$\gamma = \frac{N}{L} \cdot \|\underline{r}\|^2$$

$\underline{\mathbf{r}} = (\mathbf{r}_1,\ldots, \mathbf{r}_L)$ being a reference signal used for purposes of channel estimation and $\underline{\mathbf{e}}_{ref}$ - $(\mathbf{e}_{refstart},\ldots \mathbf{e}_{refstart+N-1})$ being a received signal part that is not influenced by data transmitted before and after the reference signal.

16. (New) The method according to claim 13, wherein:
the first estimation is given by a least squares estimation.

17. (New) The method according to claim 16, wherein:
the least squares estimation is given by

$$\hat{\underline{h}} = \left(G^{*T} \cdot G\right)^{-1} \cdot G^{*T} \cdot \underline{e}_{ref}$$

18. (New) The method according to claim 13, wherein:
the step of performing the estimation of the additive interference is given by

$$\sigma^2 = \theta \left(E - (1+ \mathrm{f}) \cdot \gamma \|\hat{\underline{h}}\|^2\right) / \left(N - (1+ \mathrm{f})\right)$$

with

$$\theta(x) = \begin{cases} x, & \text{if } x > 0 \\ \text{otherwise}, & 0 \end{cases}$$

19. (New) The method according to claim 13, wherein:

the correction of the first estimation $\hat{h}'_k$ of the k[th] component, $k \in \{1,\dots,W\}$, of estimation vector $\underline{\hat{h}}$ of the pulse response **h** is given by

$$\hat{h}'_k = \begin{cases} 0, \text{ if } h_k^2 < \sigma^2 / \gamma \\ \text{otherwise } \ h_k \end{cases}$$

20. (New) The method according to claim 13, wherein:

the correction of the first estimation $\hat{h}'_k$ of the k[th] component, $k \in \{1,\dots,W\}$, of estimation vector $\underline{\hat{h}}$ of the pulse response **h** is given by

$$\hat{h}'_k = \sqrt{\theta\left(\hat{h}_k^2 - \sigma^2 / \gamma\right)} \cdot \hat{h}_k / \left|\hat{h}_k\right| \,, \quad \text{if } \hat{h}_k \neq 0, \text{ and}$$

otherwise

$$\hat{h}'_k = 0$$

21. (New) The method according to claim 13, wherein:
the correction of the first estimation is given by a POCS algorithm.

22. (New) The method according to claim 13, wherein:
the correction of the first estimation is given by a MMSE algorithm.

23. (New) The method according to claim 22, wherein:

the MMSE algorithm is given by

$$\underline{\hat{h}} = \left(G^{*T} \cdot G + \sigma^2 \cdot \mathrm{I}\right)^{-1} \cdot G^{*T} \cdot \underline{e}_{\mathrm{ref}}$$

I being the unit matrix.

24. (New) A device for estimating a memory-enabled transmission channel, comprising:

a channel estimator;

an estimator of an additive interference, the channel estimator and the estimator of the additive interference act on a received signal; and

a channel estimation correcting element for correcting a signal of the channel estimator while taking into consideration an output signal of the estimator of the additive interference.

Remarks

This Preliminary Amendment cancels original claims 1 to 12, without prejudice, in the underlying PCT Application No. PCT/DE00/01399. The Preliminary Amendment also adds new claims 13-24. The new claims conform the claims to U.S. Patent and Trademark Office rules and do not add new matter to the application.

In accordance with 37 C.F.R. § 1.121(b)(3), the Substitute Specification (including the Abstract, but without the claims) contains no new matter. The amendments reflected in the Substitute Specification (including Abstract) are to conform the Specification and Abstract to U.S. Patent and Trademark Office rules or to correct informalities. As required by 37 C.F.R. § 1.121(b)(3)(iii) and § 1.125(b)(2), a Marked Up Version Of The Substitute Specification comparing the Specification of record and the Substitute Specification also accompanies this Preliminary Amendment. Approval and entry of the Substitute Specification (including Abstract) are respectfully requested.

The underlying PCT Application No. PCT/DE00/01399 includes an International Search Report, dated October 4, 2000, and an International Preliminary Examination Report, dated July 16, 2001, copies of which are submitted herewith.

Applicant asserts that the subject matter of the present application is new, non-obvious, and useful. Prompt consideration and allowance of the application are respectfully requested.

Respectfully Submitted,

KENYON & KENYON

By: [signature] (Reg. No. 41,172)

Dated: 11/6/01

By: Richard L. Mayer

Richard L. Mayer
(Reg. No. 22,490)

One Broadway
New York, NY 10004
(212) 425-7200

Substitute Specification

[10191/2062]

METHOD AND DEVICE FOR ESTIMATING MEMORY-ENABLED TRANSMISSION CHANNELS

Field Of The Invention

The present invention relates to a method and a device for estimating memory-enabled transmission channels as used, e.g. in discrete-time communications systems, such as CDMA systems (CDMA = code division multiple access).

Background Information

When transmitting data via memory-enabled channels, data parts separated over time are superposed. The resulting intersymbol interference of the data can be eliminated if the pulse response of the transmission channel is known. So-called channel estimators are used to determine the pulse response. They use information regarding the transmitted signal or the form of this signal to derive channel coefficients from the received signal. The most widely used channel estimators are based on a matched filter for a completely known reference signal **r** having optimum autocorrelation properties, i.e., $\mathbf{r}*\mathbf{r} \propto \delta$, as seen, for example, in K.D. Kammeyer's "Nachrichtenübertragung," 2nd Ed., Information Technology Series, Teubner, Stuttgart, 1996. Non-optimum autocorrelation properties can be linearly corrected, yet additive noise of the transmission channel to be estimated, as is inherent, e.g., in CDMA systems (CDMA = code division multiple access), generally results in coefficient estimations that are higher than the actual values. It is known to partially correct these inaccurate coefficient estimations using non-linear reworking. Thus, such a method, called the POCS method or POCS algorithm (POCS = projection onto convex sets), is known, for example, from the publication by Z. Kostic, M.I. Sezan and E.L. Titlebaum: "Estimation of the Parameters of a Multipath Channel Using Set-Theoretic Deconvolution", IEEE Trans. Comm., Vol. 40 (1992), 1006 - 1011. In this connection, reference is also made to the known MMSE algorithm (MMSE = minimum mean square error), which is described, e.g., in the K.D. Kammeyer monograph "Nachrichtenübertragung" cited above.

However, in the case of currently known corrections of additive interferences when estimating memory-enabled transmission channels, it is disadvantageous that the methods produce correction results having varying accuracy for interferences of varying intensity. Moreover, threshold operations discontinuously correct coefficient values in the vicinity of the threshold value, thereby resulting in unnecessarily bad corrections.

Summary Of The Invention

Therefore, the object of the present invention is to provide a method and a device for estimating memory-enabled transmission channels, which provides an improved estimation of the channels, the quality of the estimation being as least dependent as possible on the additive interferences of the transmission channel.

The present invention relates to a method for estimating memory-enabled transmission channels, having the following steps:

(a) Determining a first estimation $\hat{\underline{h}}$ of the transmission channel;

(b) Estimating the additive interferences of the transmission channel; and

(c) Correcting the first channel estimation of step (a) while taking into account the estimation of the additive interferences of step (b).

Preferably, in the method according to the present invention, first channel estimation $\hat{\underline{h}}$ of step (a) is carried out using a matched filter or a least squares estimation.

The device according to the present invention further includes a channel estimator and an estimator of the additive interferences acting on the received signal and further has a channel estimation correction that corrects the signal of the channel estimator while taking into the consideration the output signal of the estimator of the additive interferences.

Advantageously, the method provides improved estimations in comparison with other

methods. The estimations are relatively independent of the intensity of the additive interferences. Small channel coefficients are estimated more precisely than in customary threshold value corrections. As a result, the new method can also be used to better equalize non-Nyquist pulse shaped signals.

Brief Description Of The Drawings

Figure 1 shows a block diagram of the device according to the present invention, for estimating memory-enabled transmission channels.

Figure 2 shows the layout of a channel estimator.

Detailed Description

Figure 1 shows a channel estimator 1 as well as a parallelly situated interference estimator 2, both of which receive a received signal 4, and shows a channel estimation correcting element 3, which corrects the signal from channel estimator 1 with the aid of the output signal of interference estimator 2 and outputs channel estimation 5.

To further clarify the operating mode of the device of the present invention, a discrete-time communications system is given that transmits a reference signal $\underline{\mathbf{r}} = (\mathbf{r}_1,\ldots,\mathbf{r}_L)$ for purposes of channel estimation. A data signal $\underline{\mathbf{s}} = (\mathbf{s}_1,\ldots,\mathbf{s}_L)$, whose cross correlation to reference signal $\underline{\mathbf{r}}$ tends to zero, can optionally be transmitted at the same time. This case is representative of CDMA systems, which simultaneously transmit reference information and data information using orthogonal CDMA codes. Power P_S of data signal $\underline{\mathbf{s}}$ is f-fold power P_r of reference signal $\underline{\mathbf{r}}$, i.e., $P_S = f \cdot P_r$. In this context, the state $f = 0$ corresponds to systems that transmit reference signals and data signals separately with respect to time. The transmitted signal is transmitted via a static multi-path channel with the pulse response $\underline{\mathbf{h}} = (\mathbf{h}_1,\ldots,\mathbf{h}_W)$, W being the number of chips, and with additive Gaussian noise $\underline{\mathbf{n}}$, so that the following received signal results:

$$\underline{\mathbf{e}} = (\underline{\mathbf{r}} + \underline{\mathbf{s}}) * \underline{\mathbf{h}} + \underline{\mathbf{n}}$$

Then, $N = L - W + 1$ is the length of received signal part $\underline{\mathbf{e}}_{ref} = (\mathbf{e}_{refstart}, \ldots, \mathbf{e}_{refstart+N-1})$, which is not influenced by data transmitted before or after the reference signal. Furthermore, let $E = \left\|\underline{e}_{ref}\right\|^2$ be the entire received energy of the received signal that was influenced by the reference signal. Depending on the device, channel coefficients $\mathbf{h}_k$, $k \in \{1, \ldots, W\}$, of pulse response $\underline{\mathbf{h}}$ are initially estimated by matched filter $\underline{\mathbf{r}}^*$-k corresponding to received signal $\underline{\mathbf{r}}$ to be $\underline{\hat{h}}$:

$$\underline{\hat{h}} = \frac{1}{\gamma} \cdot G^{*T} \cdot \underline{e}_{ref} ,$$

where

$$G = \begin{pmatrix} r_W & r_{W-1} & \cdots & r_1 \\ r_{W+1} & r_w & & r_2 \\ \cdot & \cdot & & \cdot \\ r_{W+N-1} & r_{W+N-2} & \cdots & r_N \end{pmatrix}$$

and

$$\gamma = \frac{N}{L} \cdot \left\|\underline{r}\right\|^2 .$$

The layout of this estimator is represented in Figure 2.

Using the following equation, intensity σ^2 of the additive interferences is subsequently estimated to be:

$$\sigma^2 = \theta\left(\left(E-(1+\mathrm{f})\cdot\gamma\cdot\left\|\underline{\hat{h}}\right\|^2\right)/\left(N-(1+\mathrm{f})\right)\right)$$

In this context, the following definition was met:

$$\theta(x)=\begin{cases} x, & \text{if } x>0 \\ \text{otherwise,} & 0 \end{cases}$$

Subsequently, the estimated channel coefficients $\hat{h}_k$, k $\in$ {1,...,W}, of estimated pulse response $\hat{h}_k$ is corrected using the following formula:

$$\hat{h}_k' = \sqrt{\theta\left(\hat{h}_k^2 - \sigma^2/\gamma\right)} \cdot \hat{h}_k/\left|\hat{h}_k\right| \quad , \text{ if } \hat{h}_k \neq 0, \text{ and}$$

otherwise

$$\hat{h}_k' = 0$$

Figure 2 shows the calculating scheme of the above described channel estimator having a matched filter structure. Since the diagram in the above was already explained and Figure 2 is largely self-explanatory, it is not necessary to describe Figure 2.

Abstract Of The Disclosure

A method for estimating memory-enabled transmission channels, having the following steps: determining a first estimation $\underline{\hat{h}}$ of the pulse response of the transmission channel; estimating the additive interferences of the transmission channel; and correcting the first channel estimation while taking into consideration the estimation of the additive interferences.

[10191/2062]

METHOD AND DEVICE FOR ESTIMATING MEMORY-ENABLED TRANSMISSION CHANNELS

Field Of The Invention

The present invention relates to a method and a device for estimating memory-enabled transmission channels as used, e.g. in discrete-time communications systems, such as CDMA systems (CDMA = code division multiple access).

Background Information

When transmitting data via memory-enabled channels, data parts separated over time are superposed. The resulting intersymbol interference of the data can be eliminated if the pulse response of the transmission channel is known. So-called channel estimators are used to determine the pulse response. They use information regarding the transmitted signal or the form of this signal to derive channel coefficients from the received signal. The most widely used channel estimators are based on a matched filter for a completely known reference signal **r** having optimum autocorrelation properties, i.e., $\mathbf{r}^*\mathbf{r} \propto \delta$, as seen, for example, in K.D. Kammeyer's "Nachrichtenübertragung," 2nd Ed., Information Technology Series, Teubner, Stuttgart, 1996. Non-optimum autocorrelation properties can be linearly corrected, yet additive noise of the transmission channel to be estimated, as is inherent, e.g., in CDMA systems (CDMA = code division multiple access), generally results in coefficient estimations that are higher than the actual values. It is known to partially correct these inaccurate coefficient estimations using non-linear reworking. Thus, such a method, called the POCS method or POCS algorithm (POCS = projection onto convex sets), is known, for example, from the publication by Z. Kostic, M.I. Sezan and E.L. Titlebaum: "Estimation of the Parameters of a Multipath Channel Using Set-Theoretic Deconvolution", IEEE Trans. Comm., Vol. 40 (1992), 1006 - 1011. In this connection, reference [must] is also [be] made to the known MMSE algorithm (MMSE = minimum mean square error), which is described, e.g., in the K.D. Kammeyer monograph "Nachrichtenübertragung" cited above.

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However, in the case of currently known corrections of additive interferences when estimating memory-enabled transmission channels, it is disadvantageous that the methods produce correction results having varying accuracy for interferences of varying intensity. Moreover, threshold operations discontinuously correct coefficient values in the vicinity of the threshold value, thereby resulting in unnecessarily bad corrections.

Summary Of The Invention

Therefore, the object of the present invention is to provide a method and a device for estimating memory-enabled transmission channels, which provides an improved estimation of the channels, the quality of the estimation being as least dependent as possible on the additive interferences of the transmission channel.

[This objective is achieved by the method having the features of Patent Claim 1, as well as by the device having the features of Patent Claim 12. Advantageous embodiments of the present invention are the subject matter of the dependent claims.]

The present invention relates to a method for estimating memory-enabled transmission channels, having the following steps:

(a) Determining a first estimation $\underline{\hat{h}}$ of the transmission channel;

(b) Estimating the additive interferences of the transmission channel; and

(c) Correcting the first channel estimation of step (a) while taking into account the estimation of the additive interferences of step (b).

Preferably, in the method according to the present invention, first channel estimation $\underline{\hat{h}}$ of step (a) is carried out using a matched filter or a least squares estimation.

The device according to the present invention further includes a channel estimator and an estimator of the additive interferences acting on the received signal and further has a channel

estimation correction that corrects the signal of the channel estimator while taking into the consideration the output signal of the estimator of the additive interferences.

Advantageously, the method provides improved estimations in comparison with other methods. The estimations are relatively independent of the intensity of the additive interferences. Small channel coefficients are estimated more precisely than in customary threshold value corrections. As a result, the new method can also be used to better equalize non-Nyquist pulse shaped signals.

[Exemplary embodiments of the present invention are explained in greater detail in light of the drawings.] Brief Description Of The Drawings

Figure 1 shows a block diagram of the device according to the present invention, for estimating memory-enabled transmission channels[; and].

Figure 2 shows the layout of a channel estimator.

Detailed Description

Figure 1 shows a channel estimator 1 as well as a parallelly situated interference estimator 2, both of which receive a received signal 4, and shows a channel estimation correcting element 3, which corrects the signal from channel estimator 1 with the aid of the output signal of interference estimator 2 and outputs channel estimation 5.

To further clarify the operating mode of the device of the present invention, a discrete-time communications system is given that transmits a reference signal $\underline{\mathbf{r}} = (\mathbf{r}_1,\ldots,\mathbf{r}_L)$ for purposes of channel estimation. A data signal $\underline{\mathbf{s}} = (\mathbf{s}_1,\ldots,\mathbf{s}_L)$, whose cross correlation to reference signal $\underline{\mathbf{r}}$ tends to zero, can optionally be transmitted at the same time. This case is representative of CDMA systems, which simultaneously transmit reference information and data information using orthogonal CDMA codes. Power P_S of data signal $\underline{\mathbf{s}}$ is f-fold power P_r of reference signal $\underline{\mathbf{r}}$, i.e., $P_S = f - P_r$. In this context, the state $f = 0$ corresponds to systems that transmit reference signals and data signals separately with respect to time. The transmitted signal is

transmitted via a static multi-path channel with the pulse response $\underline{\mathbf{h}} = (\mathbf{h}_1,...,\mathbf{h}_W)$, W being the number of chips, and with additive Gaussian noise $\underline{\mathbf{n}}$, so that the following received signal results:

$$\underline{\mathbf{e}} = (\underline{\mathbf{r}} + \underline{\mathbf{s}}) * \underline{\mathbf{h}} + \underline{\mathbf{n}}$$

Then, $N = L - W + 1$ is the length of received signal part $\underline{\mathbf{e}}_{ref} = (\mathbf{e}_{refstart},...,\mathbf{e}_{refstart+N-1})$, which is not influenced by data transmitted before or after the reference signal. Furthermore, let $E = \left\|\underline{e}_{ref}\right\|^2$ be the entire received energy of the received signal that was influenced by the reference signal. Depending on the device, channel coefficients $\mathbf{h}_k$, $k \in \{1,...,W\}$, of pulse response $\underline{\mathbf{h}}$ are initially estimated by matched filter $\underline{\mathbf{r}}^{*}$-k corresponding to received signal $\underline{\mathbf{r}}$ to be $\underline{\hat{h}}$:

$$\underline{\hat{h}} = \frac{1}{\gamma} \cdot G^{*T} \cdot \underline{e}_{ref},$$

where

$$G = \begin{pmatrix} r_W & r_{W-1} & \cdots & r_1 \\ r_{W+1} & r_w & & r_2 \\ . & . & & . \\ r_{W+N-1} & r_{W+N-2} & \cdots & r_N \end{pmatrix}$$

and

$$\gamma = \frac{N}{L} \cdot \left\|\underline{r}\right\|^2.$$

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The layout of this estimator is represented in Figure 2.

Using the following equation, intensity σ^2 of the additive interferences is subsequently estimated to be:

$$\sigma^2 = \theta\left(E - (1+\mathrm{f})\cdot\gamma\cdot\left\|\hat{\underline{h}}\right\|^2\right) / \left(N - (1+\mathrm{f})\right)$$

In this context, the following definition was met:

$$\theta(x) = \begin{cases} x, \text{ if } x > 0 \\ \text{otherwise, } 0 \end{cases}$$

Subsequently, the estimated channel coefficients $\hat{h}_k$, $k \in \{1,\ldots,W\}$, of estimated pulse response $\hat{h}_k$ is corrected using the following formula:

$$\hat{h}_k^{'} = \sqrt{\theta\left(\hat{h}_k^2 - \sigma^2 / \gamma\right)} \cdot \hat{h}_k / \left|\hat{h}_k\right| \quad , \quad \text{if } \hat{h}_k \neq 0, \text{ and}$$

otherwise

$$\hat{h}_k^{'} = 0$$

Figure 2 shows the calculating scheme of the above described channel estimator having a matched filter structure. Since the diagram in the above was already explained and Figure 2 is largely self-explanatory, it is not necessary to describe Figure 2.

Abstract Of The Disclosure

A [The present invention relates to a] method for estimating memory-enabled transmission channels, having the following steps: [(a)] determining a first estimation $\underline{\hat{h}}$ of the pulse response of the transmission channel; [(b)] estimating the additive interferences of the transmission channel; and [(c)] correcting the first channel estimation [of step (a)] while taking into consideration the estimation of the additive interferences [of step (b)].

[[Fig. 1]]

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[10191/2062]

METHOD AND DEVICE FOR ESTIMATING MEMORY-ENABLED TRANSMISSION CHANNELS

The present invention relates to a method and a device for estimating memory-enabled transmission channels as used, e.g. in discrete-time communications systems, such as CDMA systems (CDMA = code division multiple access).

When transmitting data via memory-enabled channels, data parts separated over time are superposed. The resulting intersymbol interference of the data can be eliminated if the pulse response of the transmission channel is known. So-called channel estimators are used to determine the pulse response. They use information regarding the transmitted signal or the form of this signal to derive channel coefficients from the received signal. The most widely used channel estimators are based on a matched filter for a completely known reference signal **r** having optimum autocorrelation properties, i.e., $\mathbf{r}^*\mathbf{r} \propto \delta$, as seen, for example, in K.D. Kammeyer's "Nachrichtenübertragung," 2nd Ed., Information Technology Series, Teubner, Stuttgart, 1996. Non-optimum autocorrelation properties can be linearly corrected, yet additive noise of the transmission channel to be estimated, as is inherent, e.g., in CDMA systems (CDMA = code division multiple access), generally results in coefficient estimations that are higher than the actual values. It is known to partially correct these inaccurate coefficient estimations using non-linear reworking. Thus, such a method, called the POCS method or POCS algorithm (POCS = projection onto convex sets), is known, for example, from the publication by Z. Kostic, M.I. Sezan and E.L. Titlebaum: "Estimation of the Parameters of a Multipath Channel Using Set-Theoretic Deconvolution", IEEE Trans. Comm., Vol. 40 (1992), 1006 - 1011. In this connection, reference must also be made to the known MMSE algorithm (MMSE = minimum mean square error), which is described, e.g., in the K.D. Kammeyer monograph "Nachrichtenübertragung" cited above.

However, in the case of currently known corrections of additive interferences when estimating memory-enabled transmission channels, it is disadvantageous that the methods produce correction results having varying accuracy for interferences of varying intensity. Moreover, threshold operations discontinuously correct coefficient values in the vicinity of

the threshold value, thereby resulting in unnecessarily bad corrections.

Therefore, the object of the present invention is to provide a method and a device for estimating memory-enabled transmission channels, which provides an improved estimation of the channels, the quality of the estimation being as least dependent as possible on the additive interferences of the transmission channel.

This objective is achieved by the method having the features of Patent Claim 1, as well as by the device having the features of Patent Claim 12. Advantageous embodiments of the present invention are the subject matter of the dependent claims.

The present invention relates to a method for estimating memory-enabled transmission channels, having the following steps:

(a) Determining a first estimation $\underline{\hat{h}}$ of the transmission channel;

(b) Estimating the additive interferences of the transmission channel; and

(c) Correcting the first channel estimation of step (a) while taking into account the estimation of the additive interferences of step (b).

Preferably, in the method according to the present invention, first channel estimation $\underline{\hat{h}}$ of step (a) is carried out using a matched filter or a least squares estimation.

The device according to the present invention further includes a channel estimator and an estimator of the additive interferences acting on the received signal and further has a channel estimation correction that corrects the signal of the channel estimator while taking into the consideration the output signal of the estimator of the additive interferences.

Advantageously, the method provides improved estimations in comparison with other methods. The estimations are relatively independent of the intensity of the additive interferences. Small channel coefficients are estimated more precisely than in customary threshold value corrections. As a result, the new method can also be used to better equalize

non-Nyquist pulse shaped signals.

Exemplary embodiments of the present invention are explained in greater detail in light of the drawings.

Figure 1 shows a block diagram of the device according to the present invention, for estimating memory-enabled transmission channels; and

Figure 2 shows the layout of a channel estimator.

Figure 1 shows a channel estimator 1 as well as a parallelly situated interference estimator 2, both of which receive a received signal 4, and shows a channel estimation correcting element 3, which corrects the signal from channel estimator 1 with the aid of the output signal of interference estimator 2 and outputs channel estimation 5.

To further clarify the operating mode of the device of the present invention, a discrete-time communications system is given that transmits a reference signal $\underline{\mathbf{r}} = (\mathbf{r}_1,\ldots,\mathbf{r}_L)$ for purposes of channel estimation. A data signal $\underline{\mathbf{s}} = (\mathbf{s}_1,\ldots,\mathbf{s}_L)$, whose cross correlation to reference signal $\underline{\mathbf{r}}$ tends to zero, can optionally be transmitted at the same time. This case is representative of CDMA systems, which simultaneously transmit reference information and data information using orthogonal CDMA codes. Power P_S of data signal $\underline{\mathbf{s}}$ is f-fold power P_r of reference signal $\underline{\mathbf{r}}$, i.e., $P_S = f - P_r$. In this context, the state f = 0 corresponds to systems that transmit reference signals and data signals separately with respect to time. The transmitted signal is transmitted via a static multi-path channel with the pulse response $\underline{\mathbf{h}} = (\mathbf{h}_1,\ldots,\mathbf{h}_W)$, W being the number of chips, and with additive Gaussian noise $\underline{\mathbf{n}}$, so that the following received signal results:

$$\underline{\mathbf{e}} = (\underline{\mathbf{r}} + \underline{\mathbf{s}}) * \underline{\mathbf{h}} + \underline{\mathbf{n}}$$

Then, N = L - W + 1 is the length of received signal part $\underline{\mathbf{e}}_{ref} = (\mathbf{e}_{refstart},\ldots,\mathbf{e}_{refstart+N-1})$, which is not influenced by data transmitted before or after the reference signal. Furthermore, let E $= \left\|\underline{e}_{ref}\right\|^2$ be the entire received energy of the received signal that was influenced by the

reference signal. Depending on the device, channel coefficients $\mathbf{h}_k$, $k \in \{1,\ldots,W\}$, of pulse response $\underline{\mathbf{h}}$ are initially estimated by matched filter $\underline{\mathbf{r}}^*$-k corresponding to received signal $\underline{\mathbf{r}}$ to be $\hat{\underline{h}}$:

$$\hat{\underline{h}} = \frac{1}{\gamma} \cdot G^{*T} \cdot \underline{e}_{\text{ref}},$$

where

$$G = \begin{pmatrix} r_W & r_{W-1} & \cdots & r_1 \\ r_{W+1} & r_w & & r_2 \\ . & . & & . \\ r_{W+N-1} & r_{W+N-2} & \cdots & r_N \end{pmatrix}$$

and

$$\gamma = \frac{N}{L} \cdot \left\|\underline{r}\right\|^2 .$$

The layout of this estimator is represented in Figure 2.

Using the following equation, intensity σ^2 of the additive interferences is subsequently estimated to be:

$$\sigma^2 = \theta\left(E - (1+\mathrm{f}) \cdot \gamma \cdot \left\|\hat{\underline{h}}\right\|^2\right) / \left(N - (1+\mathrm{f})\right)$$

In this context, the following definition was met:

$$\theta(x) = \begin{cases} x, & \text{if } x > 0 \\ \text{otherwise,} & 0 \end{cases}$$

Subsequently, the estimated channel coefficients $\hat{h}_k$, k ∈ {1,...,W}, of estimated pulse response $\hat{h}_k$ is corrected using the following formula:

$$\hat{h}_k' = \sqrt{\theta\left(\hat{h}_k^2 - \sigma^2 / \gamma\right)} \cdot \hat{h}_k / \left|\hat{h}_k\right| \quad , \quad \text{if } \hat{h}_k \neq 0, \text{ and}$$

otherwise

$$\hat{h}_k' = 0$$

Figure 2 shows the calculating scheme of the above described channel estimator having a matched filter structure. Since the diagram in the above was already explained and Figure 2 is largely self-explanatory, it is not necessary to describe Figure 2.

What is claimed is:

1. A method for estimating a memory-enabled transmission channel, wherein the method has the following steps:

   (a) determining a first estimation $\underline{\hat{h}}$ of the pulse response of the transmission channel;

   (b) estimating the additive interferences of the transmission channel; and

   (c) correcting the first channel estimation of step (a) while taking into consideration the estimation of the additive interferences of step (b).

2. The method as recited in Claim 1, wherein the first channel estimation $\underline{\hat{h}}$ of step (a) is performed by a matched filter.

3. The method as recited in Claim 2, wherein the matched filter is given by

$$\underline{\hat{h}} = \frac{1}{\gamma} \cdot G^{*T} \cdot \underline{e}_{\mathrm{ref}},$$

where

$$G = \begin{pmatrix} r_W & r_{W-1} & \cdots & r_1 \\ r_{W+1} & r_w & & r_2 \\ \cdot\,\cdot & \cdot & & \cdot \\ r_{W+N-1} & r_{W+N-2} & \cdots & r_N \end{pmatrix}$$

and

$$\gamma = \frac{N}{L} \cdot \|\underline{r}\|^2$$

$\underline{\mathbf{r}} = (\mathbf{r}_1,..., \mathbf{r}_L)$ being a reference signal used for purposes of channel estimation and $\underline{\mathbf{e}}_{ref}$ - ($\mathbf{e}_{refstart},.. \mathbf{e}_{refstart+N-1}$) being the received signal part that is not influenced by the data transmitted before and after the reference signal.

4. The method as recited in Claim 1, wherein the first channel estimation of step (a) is given by a least squares estimation.

5. The method as recited in Claim 4, wherein the least squares estimation is given by

$$\hat{\underline{h}} = \left(G^{*T} \cdot G\right)^{-1} \cdot G^{*T} \cdot \underline{e}_{ref}$$

6. The method as recited in one of the preceding claims, wherein the interference estimation in step (b) is given by

$$\sigma^2 = \theta\left(E - (1+\mathrm{f}) \cdot \gamma\left\|\hat{\underline{h}}\right\|^2\right) / \left(N - (1+\mathrm{f})\right)$$

with

$$\theta(x) = \begin{cases} x, \ \text{if}\, x > 0 \\ \text{otherwise}, \ 0 \end{cases}$$

7. The method as recited in one of the preceding claims, wherein the channel estimation correction $\hat{h}_k'$ of the k[th] component, $k \in \{1,...,W\}$, of the estimation vector $\hat{\underline{h}}$ of the channel pulse response $\underline{\mathbf{h}}$ of step (c) is given by

$$\hat{h}_k' = \begin{cases} 0, \ \text{if}\, h_k^2 < \sigma^2 / \gamma \\ \text{otherwise} \ h_k \end{cases}$$

8. The method as recited in one of Claims 1 through 6, wherein the channel estimation correction $\hat{h}_k'$ of the k[th] component, $k \in \{1,...,W\}$, of the estimation vector $\underline{\hat{h}}$ of the channel pulse response $\underline{\mathbf{h}}$ of step (c) is given by

$$\hat{h}_k' = \sqrt{\theta\left(\hat{h}_k^2 - \sigma^2 / \gamma\right)} \cdot \hat{h}_k / \left|\hat{h}_k\right|, \quad \text{if } \hat{h}_k \neq 0, \text{ and}$$

otherwise

$$\hat{h}_k' = 0$$

9. The method as recited in one of Claims 1 through 6, wherein the channel estimation correction from step (c) is given by the POCS algorithm.

10. The method as recited in one of Claims 1 through 6, wherein the channel estimation correction from step (c) is given by the MMSE algorithm.

11. The method as recited in Claim 10, wherein the MMSE algorithm is given by

$$\underline{\hat{h}'} = \left(G^{*T} \cdot G + \sigma^2 \cdot \mathrm{I}\right)^{-1} \cdot G^{*T} \cdot \underline{e}_{ref}$$

I being the unit matrix.

12. A device for implementing the method as recited in one of the preceding claims, wherein the device includes a channel estimator (1) and an estimator of the additive interferences (2), both of which act on the received signal, and also includes a channel estimation correcting element (3), which corrects the signal of the channel estimator

(1) while taking into consideration the output signal of the estimator of the additive interferences (2).

Abstract

The present invention relates to a method for estimating memory-enabled transmission channels, having the following steps:

(a) determining a first estimation $\underline{\hat{h}}$ of the pulse response of the transmission channel;

(b) estimating the additive interferences of the transmission channel; and

(c) correcting the first channel estimation of step (a) while taking into consideration the estimation of the additive interferences of step (b).

[Fig. 1]

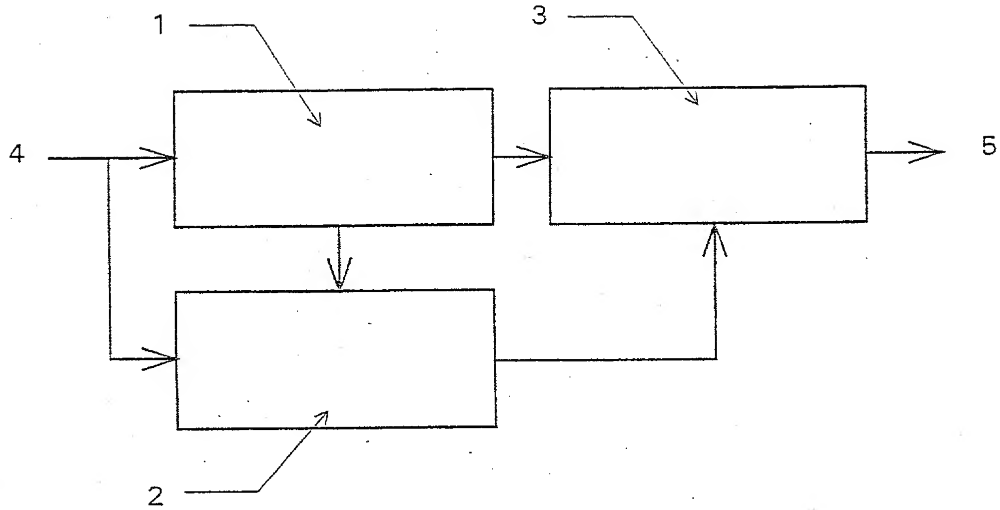
1
3
4
5
2

Fig.1

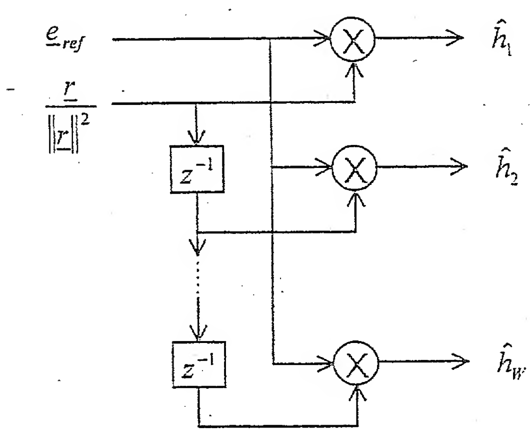
$\underline{e}_{ref}$
$\frac{\underline{r}}{\|\underline{r}\|^2}$
z^{-1}
z^{-1}
$\hat{h}_1$
$\hat{h}_2$
$\hat{h}_W$

Fig.2

#4

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COMBINED DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below adjacent to my name.

I believe I am the original, first and sole inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled **METHOD AND DEVICE FOR ESTIMATING MEMORY-ENABLED TRANSMISSION CHANNELS**, the specification of which was filed as International Application No. PCT/DE00/01399 on the 4th day of May, 2000.

10040538.040402

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a). I hereby claim foreign priority benefits under Title 35, United States Code § 119 of any foreign application(s) for patent or inventor's certificate or of any PCT international applications(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

~~EV003627534US~~

PRIOR FOREIGN/PCT APPLICATION(S)
<u>AND ANY PRIORITY CLAIMS UNDER 35 U.S.C. § 119</u>

Country : Federal Republic of Germany

Application No. : 199 20 819.0

Date of Filing: May 6, 1999

Priority Claimed
Under 35 U.S.C. § 119 : [X] Yes [ ] No

I hereby claim the benefit under Title 35, United States Code § 120 of any United States Application or PCT International Application designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code § 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations § 1.56(a) which occurred between the filing date of the prior application(s) and the national or PCT international filing date of this application:

PRIOR U.S. APPLICATIONS OR
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DESIGNATING THE U.S. FOR BENEFIT UNDER 35 U.S.C. § 120

<u>U.S. APPLICATIONS</u>

Number :

Filing Date :

PCT APPLICATIONS
<u>DESIGNATING THE U.S.</u>

PCT Number :

PCT Filing Date :

I hereby appoint the following attorney(s) and/or agents to prosecute the above-identified application and transact all business in the Patent and Trademark Office connected therewith.

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

1-00

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